

# RF MEMS and Their Applications in NASA's Space Communication Systems

W. Daniel Williams<sup>1</sup>, George E. Ponchak<sup>1</sup>, Rainee N. Simons<sup>2</sup>, Afroz Zaman<sup>1</sup>, Carol Kory<sup>3</sup>, Edwin Wintucky<sup>1</sup>, Jeffrey D. Wilson<sup>1</sup>, Maximilian C. Scardelletti<sup>1</sup>, Richard Lee<sup>1</sup>, and Hung Nguyen<sup>1</sup>

1. NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135
2. Dynacs Engineering Company Inc., NASA Glenn Research Center, Cleveland, OH 44135
3. Analex Corporation, NASA Glenn Research Center, Cleveland, OH 44135

RF and microwave communication systems rely on frequency, amplitude, and phase control circuits to efficiently use the available spectrum. Phase control circuits are required for electronically scanning phase array antennas that enable radiation pattern shaping, scanning, and hopping. Two types of phase shifters, which are the phase control circuits, are most often used. The first is comprised of two circuits with different phase characteristics such as two transmission lines of different lengths or a high pass and low pass filter and a switch that directs the RF power through one of the two circuits. Alternatively, a variable capacitor, or varactor, is used to change the effective electrical path length of a transmission line, which changes the phase characteristics. Filter banks are required for the diplexer at the front end of wide band communication satellites. These filters greatly increase the size and mass of the RF /microwave systems, but smaller diplexers may be made with a low loss varactor or a group of capacitors, a switch and an inductor.

Traditionally, solid-state electronic devices such as GaAs MESFETs and varactor diodes are used for these purposes. While these devices have performed well and enabled great leaps in radar and communication technologies, they do have several problems. They rely on control of current through a semiconductor junction or a metal/semiconductor junction. There is a resistive loss associated with charge flow through the junctions, and this resistive loss consumes substantial DC and RF power. For example, approximately 0.5 dB of RF power is lost through each GaAs MESFET switch. This consumed power generates heat that must be dissipated, which adds to the system size and complexity. Lastly, transistors and diodes are nonlinear devices. Linearity is required for modern, wide band communication systems that must process signals with a wide dynamic range.

RF/microwave MicroElectroMechanical (MEMS) devices were first demonstrated by Larson in 1991 [1] to be an alternative to solid-state devices for switches and varactors. Since that first paper, several variations of RF MEMS devices have been demonstrated including rotary switches [1], single supported cantilever metal-to-metal contact switches [2], double supported cantilever capacitive switches [3,4], and varactors [1]. Each of these devices share common virtues. They require high DC bias voltages ( $10 < V_{\text{bias}} < 100$  V), but they draw nearly zero current and therefore consume negligible DC power. They have high linearity because they rely on simple metal-to-metal contacts or metal-insulator-metal (MIM) capacitors. These junctions also have very low loss to RF

power, MEMS switches with 0.1 dB of insertion loss have been demonstrated at 30 GHz [3]. Lastly, and more importantly, MEMS devices may enable novel circuit and system designs and concepts that have not been possible before. For example, microfabrication processes developed for MEMS fabrication may be used to fabricate intricate metal shapes that cannot be fabricated using standard machining, such as novel RF high power amplifier circuit designs promising superior performance, but prohibited by conventional fabrication techniques.

NASA Glenn Research Center (GRC) has been actively fabricating, designing, and characterizing RF MEMS devices since 1997 for the advancement of space communication systems such as phased array antennas and receiver front ends. In this paper, we will present an overview of the development of RF MEMS switches, actuators, and varactors for frequency and phase reconfigurable components in NASA missions, their expected impact on communication systems, and issues that must be solved before MEMS devices may be fully utilized. In addition, a description of the use of microfabrication techniques to build a novel "finned-ladder Traveling Wave Tube (TWT) slow-wave structure" for more efficient, smaller size, lower cost power amplifiers at Ka-Band is presented.

#### REFERENCES

1. L. E. Larson, R. H. Hackett, M. A. Melendes, R. F. Lohr, "Micromachined microwave actuator (MIMAC) technology- a new tuning approach for microwave integrated circuits," *IEEE 1991 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest*, Boston, MA, June 10-11, 1991, pp. 27-30.
2. D. Hyman, A. Schmitz, B. Warneke, T. Y. Hsu, J. Lam, J. Brown, J. Schaffner, A. Walston, R. Y. Loo, G. L. Tangonan, M. Mehregany, and J. Lee, "GaAs-compatible surface-micromachined RF MEMS switches," *Electronics Letters*, Vol. 35, No. 3, pp. 224-225, Feb. 4, 1999.
3. S. P. Pacheco and L. P. B. Katehi, "Microelectromechanical K-Band switching circuits," *29<sup>th</sup> European Microwave Conference Digest*, Munich, Germany, October 5-7, 1999, pp. 45-48.
4. Z. J. Yao, S. Chen, S. Eshelman, D. Denniston, and C. Goldsmith, "Micromachined low-loss microwave switches," *IEEE Journ. Microelectromechanical Systems*, Vol. 8, No. 2, pp. 129-134, June 1999.